unit IV

FIBER OPTIC RECEIVER & MEASUREMENTS

This chapter covers

⇒ Fundamental Rx operation

⇒ Pre amplifier

⇒ Error sources

⇒ Rx config

⇒ Probability of Error

⇒ Quantum limit

Fundamentals Rx operation

- The design of optical Rx is much more complicated than that of an optical tx
- B'cos the Rx must first detect weak signal, distorted signal & then make decision on what type of data was sent based on an amplified version of the distorted sig.
- when the optical data are incident on the APD, higher current pulse flow through the circuit.
- the photo current is amplified by the preamplifier

⇓

It converts the voltage pulses to have adequate voltage level.

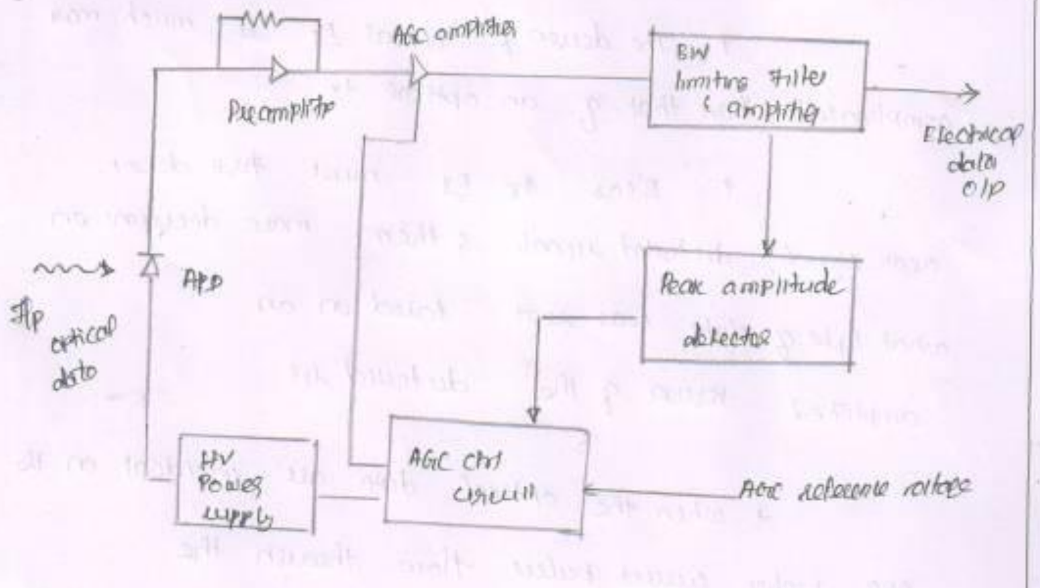


Fig: Fiber optic line Rr

⇒ The peak amplitude of the voltage pulses are maintained as constant by the AGC ctrlled amplifier

⇒ The signal from the o/p of AGC amplifier is fed back to the AGC amplifier via a peak amplitude detector

⇒ A comperation is made b/w the i/p & reference voltage level & req o/p sgl is generated which ctrl the gain of the AGC amplifier

⇒ .

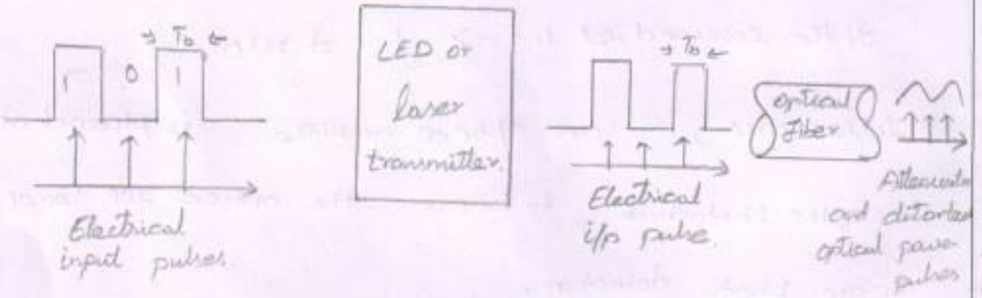


Fig: optical tx

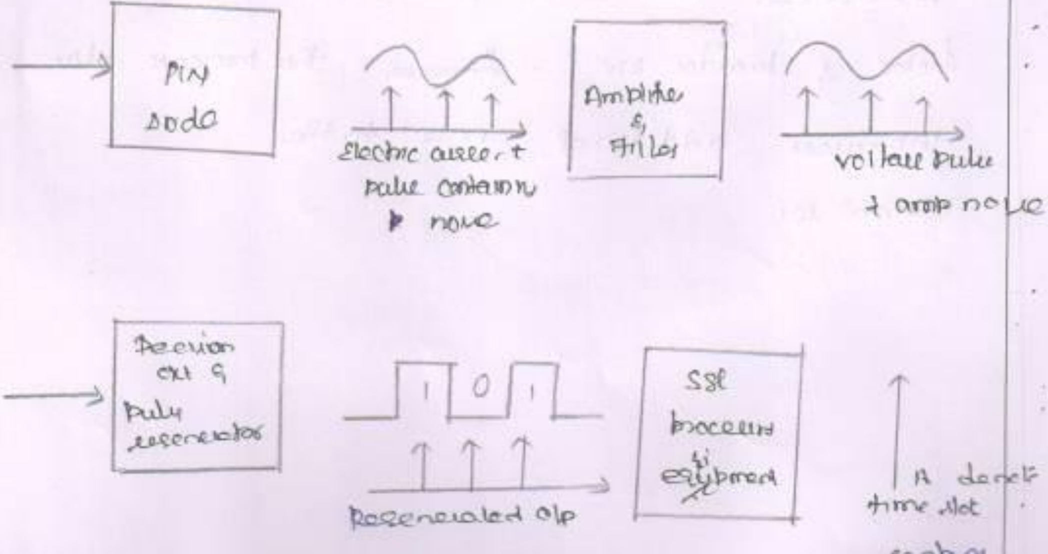


Fig: optical Rx

Threshold level:

It compares the sl in each time slot w/ a certain reference voltage known as threshold level.

* Rxd sl > threshold = 1

* Rxd sl < threshold = 0

If the received sl is > 1 ≠ zero

In some case, an optical amplifier is placed ahead of the photodiode to boost the optical sl level before photo detection.

An optical preamplifier provides a larger gain factor & broader BW. However, this process also introduces additional noise to the optical sl.

Bit Period:

=) The transmitted sig is a 2-level binary data stream consisting of either 0 or 1 in a time slot of duration To. This time slot is referred to a bit Period.

=) one of the simplest technique for sending binary data is amplitude shift keying, wherein a voltage level is switched b/w two values, which are usually on or off.

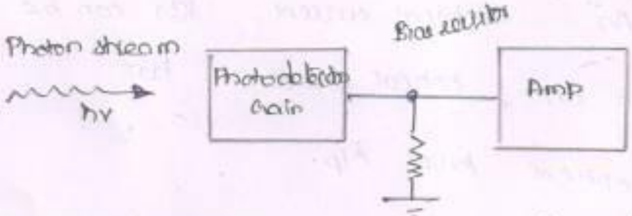
=) The optical tx converts the electrical sig into optical sig. An electrical current i(t) can be used to modulate an optical source to produce an optical power o/p.

=) optical sig equivalent for 1 is pulse of optical power of duration To whereas '0' is absence of light. The optical pulse gets attenuated as it propagate in the fiber.

⇒ P-i-n or avalanche photodiode at the Rx, convert the optical sig to electrical sig. Amplified & filtered sig are compared in a decision ckt w/ the threshold voltage.

Error sources

It can arise from various noise & disturbances associated w/ signal detection system.

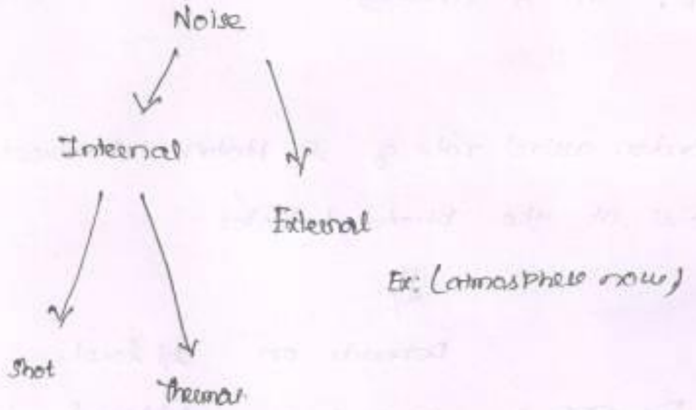


- Photon detection quantum noise
- Thermal Noise
- Amplifier noise

* Bulk dark current
* surface leakage current
* Gain

Noise:

⇒ Noise source can be either external or internal to the system



Internal noise:

⇒ It is caused by the spontaneous fluctuation of current or voltage in electric circuits.

⇒ Two types

they are

⇒ shot noise

⇒ thermal noise

shot noise arises in electronic devices b'cos of the discrete nature of current flow in the device

Thermal noise arises from the random motion of e^{ns} in a conductor.

⇒ Random arrival rate of sig photons produces a quantum noise at the photo detector.

⇓

Depends on sig level.

⇒ For APD & photodiodes additional shot noise arises from the statistical nature of the multiplication process.

Increasing avalanche gain (M) ↑

the noise level also ↑

⇒ Dark current & surface leakage current noise are independent of the photons. Thermal noise are arising from the detector load resistor & from the amplifier e^{ns}.

⇒ The primary photocurrent generated by the photodiode is a time varying Poisson process resulting from the random arrival of photons at the detector.

⇒ If the detector is illuminated by optical pol P(t) then the avg no of (e-h pair) pairs $\bar{N}$ generated in a time 'τ' is.

$$\bar{N} = \frac{\eta}{h\nu}\int_0^{\tau} P(t)\,dt$$

$$= \frac{\eta E}{h\nu}$$

η ⇒ Detector quantum η

$h\nu$ = Photon energy ,

E ⇒ Energy Rxd in a time interval τ.

The actual no of e^--hole pairs 'n' that are generated fluctuate from the average according to the poisson distribution

$$P_r(n) = \bar{N}_n \frac{e^{-\bar{N}}}{n!}$$

$P_r(n)$ = prob of 'n' e^{-ns} are emitted in an interval 't'

The random nature of the avalanche multiplication process gives rise to a type of shot noise.

A detector w/ mean avalanche gain M and an ionization rate ratio 'k', the excess noise factor F(M) for e^n injection is

$$F(M) = kM + \left(2 - {}^{1}/_{M}\right) (1-k)$$

ISI (Inter symbol Interference)

⇒ when the pulses spreading in the optical fiber, ISI will be occur.

⇒ when a pulse is txd in a given time slot, most of the pulse energy will receive in the corresponding time slot at the receiver.

However, b'coz of pulse spreading induced by the receiver, some of the txd energy will progressively spread in to neighbouring time slots as the pulse propagate along with the fiber.

The presence of this energy in an adjacent time slots results in an interfering signal.

It is called as "Intersymbol Interference" or "ISI".

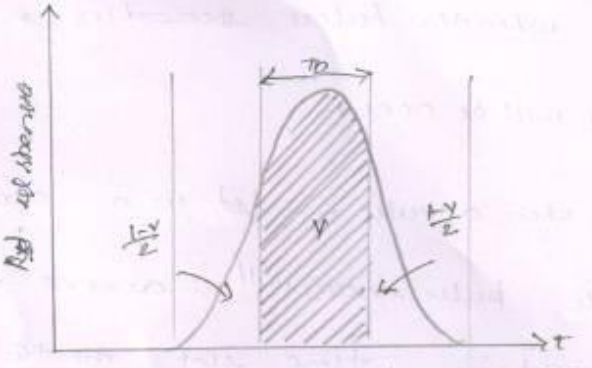


Fig: Pulse spreading in an optical signal that leads to ISI

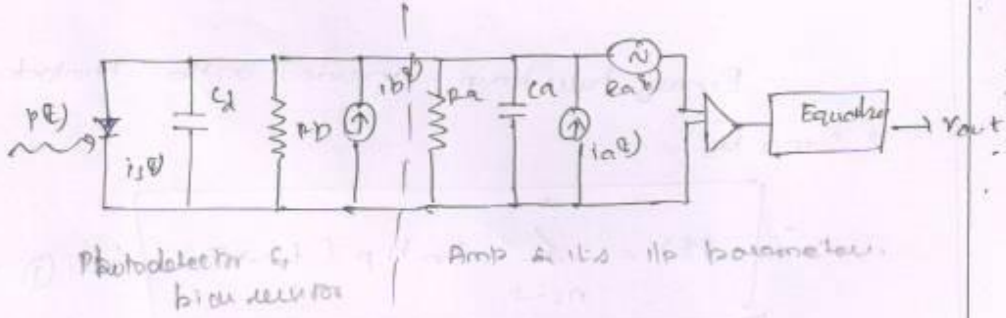
Receiver configuration:

The three basic stages of the Rx are

⇒ Photo detector
⇒ An amplifier &
⇒ An equalizer.

The PD can be either an avalanche photo diode w/ gain $M=1$ or PIN PD with gain $M=1$

PD has a quantum η & C_d (capacitor).



Amplifying function is represented by the voltage controlled current source which is characterized by a trans conductance g_m.

Two amplifier noise sources are there

⇓

→ Thermal noise due to resistor R_a

→ Noise voltage source $e_a(t)$.

These noise sources are assumed to be Gaussian in statistics & have flat spectrum & hence known as white noise.

Expression for mean o/p from PD :

Binary pulse train incident on the photodiode is given by

$$\boxed{P(t) = \sum_{n=-\infty}^{\infty} b_n h_p(t - nT_b)} \quad ①$$

P(t) : Rxd optical power

b_n :) Amplitude of n^{th} message digit

T_b :) bit Period.

$h_p(t)$:) Rxd pulse shape.

$$\boxed{\int_{-\infty}^{\infty} h_p(t)\,dt = 1} \quad ②$$

$$\Downarrow$$

Non negative PD input pulse normalised to have unit area

The mean o/p current from the PD at time 't' due to pulse train is given by.

$$\langle i(t)\rangle = \frac{\eta q}{h\nu} M P(t) \quad ③$$

sub ① in ②, we get

$$i(t) = R_0 M \sum_{n=-\infty}^{\infty} b_n h_p(t - nT_b)$$

$$\left[\because R_0 = \eta q / h\nu\right]$$

where η = quantum η.

R_0 = Responsivity of the detector.

quantum limit

For an ideal PD, which has unity quantum η & which produce no dark current (no electron hole generated).

So, in this condition, it is possible to find the minimum received optical power required for a specific bit error rate performance in a digital system

quantum limit

$$\boxed{P_r(0) = e^{-\bar{N}}}$$

$\Downarrow$

Through which we can find quantum limit